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PLASMA BOUNDARIES IN SPACE

Aerospace Corporation
El Segundo, California

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Plasma Boundaries in Space

Space Sciences Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, Calif. 90245

9 November 1976

Interim Report

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FOR THE COMMANDER

Jean Bogert

Jean Bogert
1st Lt, U.S. Air Force
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Deputy for Advanced Space Programs

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This work is primarily a survey and review of recent theoretical progress in the identification and characterization of plasma boundaries in space. The specification of such boundaries is an essential step in the formulation of self-consistent Vlasov equilibria, which is (in turn) prerequisite to an analysis of the stability of plasma boundaries against small perturbations. One type of plasma boundary is the heliomagnetic neutral sheet that arises in magnetohydrodynamic (MHD) models of the expanding solar corona (solar

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wind). The neutral sheet is annular in shape and separates the plasmas flowing from the two hemispheres (northern and southern) of the sun. The two plasmas are separated at the sun by an equatorial arcade of closed field lines along which the solar wind cannot flow. Such a model makes plausible the observation that solar wind velocities are anomalously low at sector boundaries, i.e., at traversals of the neutral sheet. Global-scale asymmetries in the photospheric B field should tend to warp the neutral sheet relative to the dipole equator. The heliomagnetic neutral sheet extends 2π radians in azimuth, and thus differs from the azimuthally limited geomagnetic neutral sheet, which can (and does) support an electrostatic field in the direction of the sheet current. The presence of such an electrostatic field (and of the azimuthal asymmetry that allows it) serves to complicate the description of the Vlasov equilibrium. The electrostatic field seems to be generated by plasma-dynamical interactions which occur on the boundary of the magnetosphere, and which are modulated by the direction of the interplanetary magnetic field. When superimposed on the electric field induced by planetary rotation, the above-described "convection" electric field produces interesting cold-plasma ($\mathbf{E} \times \mathbf{B}$) drift patterns on both closed and open field lines. The superposition is responsible for the appearance of a plasmapause on closed field lines, and the shape of the plasmapause is determined by the radial variation and magnitude of the electrostatic potential associated with the "convection" electric field. The plasmapause is a boundary for cold-plasma drift. Comparable boundaries for hot plasma can be identified by including the gradient-curvature drift in superposition with the $\mathbf{E} \times \mathbf{B}$. Application of these concepts to the magnetosphere of Jupiter reveals drift paths in the zenomagnetic tail that are adiabatically isolated from the surrounding magnetosheath. Such trajectories can be populated only by plasma of Jovian origin, or by magnetosheath plasma that has diffused across much of the zenomagnetic tail.

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INTRODUCTION

Plasma boundaries play a decisive role in space physics. For the observationalist they represent "landmark" surfaces across which particle populations and plasma-wave phenomena often vary quite drastically. For the theorist they represent partitions between regions of space in which very different dynamical interactions can occur. Moreover, plasma boundaries can be of intrinsic theoretical and observational interest because of dynamical phenomena that are unique to interfaces and that cannot occur in the relatively uniform plasmas on either side. Such phenomena ultimately impart structure to plasma boundaries and require one to speak rather of "plasma boundary layers" in space. Thus, the "boundary" comes to be recognized as the theoretical idealization, whereas the "boundary layer" takes on a genuine observational significance.

There are many examples of idealized plasma boundaries in space. A planetary magnetopause, for instance, separates the outward-flowing magnetosheath plasma from the stationary (or convected) magnetospheric plasma. In the "closed model" the magnetopause also separates the interplanetary (solar) magnetic field from the planetary magnetic field. The bow shock (detached and upstream from the magnetopause) separates the relatively undisturbed interplanetary solar-wind flow from the partially thermalized magnetosheath plasma (see Figure 1). The heliopause (not shown in Figure 1) is a shock (evidently of radius $r \sim 100$ AU) believed to separate the relatively undisturbed solar-wind flow from the thermalized interstellar plasma. Sector boundaries separate regions in which the radial component (B_r) of the interplanetary magnetic field is positive from regions in which $B_r < 0$. Localized discontinuities in the magnitude and/or direction of $\underset{\sim}{B}$ often seem to accompany (or propagate in) the solar wind as interplanetary disturbances. Within a rotating magnetosphere, one may find a virtual discontinuity (known as the plasmapause) in the density of cold ($\sim$ 1-eV) plasma. Beyond the plasmapause one may find a sharp gradient in the density of hot ($\sim$ 10-keV) plasma associated with the plasma sheet. The plasma sheet carries an azimuthal electric

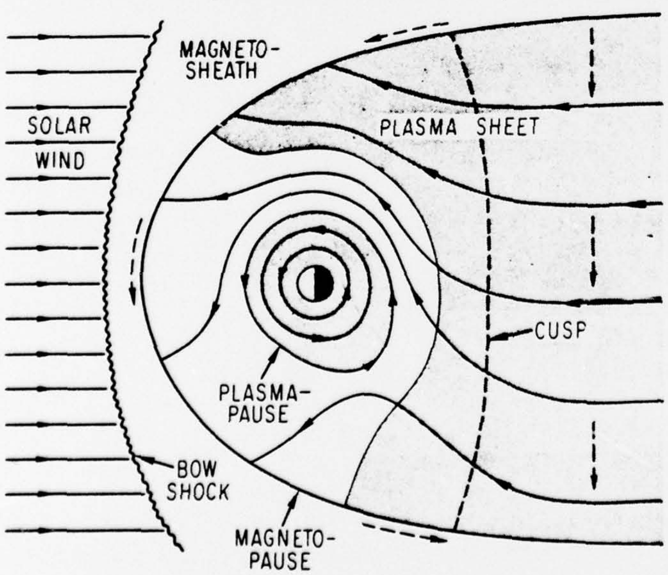

Figure 1. Distribution (shaded areas) and flow pattern (solid arrows) of magnetospheric plasma in the equatorial plane. Dashed arrows indicate electric-current pattern. The plasmasphere is the shaded region inside the plasmapause. Field lines beyond the magnetic cusp are "open", forming a neutral-sheet configuration maintained by plasma sheet currents. The plasma sheet extends also onto closed field lines.

current (see Figure 1) that supports a virtual discontinuity in the direction of $\underset{\sim}{B}$ beyond some "cusped" field line on any nightside meridian. Field lines emanating from the planet poleward of the "cusped" field lines are ideally open and form the planet's magnetic tail. Such field lines can carry an outflow of ionospheric plasma known as the polar wind, but they can also support a convective plasma flow (across $\underset{\sim}{B}$) analogous to that which occurs on closed field lines. Convection on open field lines generally proceeds toward the neutral sheet (which separates the two lobes of the tail) but is profoundly affected by planetary rotation, as will be seen below. Convection in general is driven by an electrostatic field that seems to result from a dissipative interaction between the interplanetary plasma and the magnetospheric plasma in the presence of their respective $\underset{\sim}{B}$ fields. The magnetospheric mapping of electrostatic fields is contingent on the conductivity of the magnetospheric-ionospheric plasma, which ultimately fails at the bottom of the ionosphere because of recombination.

The present work is primarily a survey and review of recent theoretical progress in the identification and characterization of these various plasma boundaries in space. It should be unnecessary to remark that there exists no overall theory of such plasma boundaries in general. There are some unifying principles, of course, but one really must construct each type of plasma boundary on paper in order to identify the plasma-dynamical interactions that affect it. Questions of stability can be addressed only within the framework of an utterly self-consistent Vlasov (or collisional) equilibrium that includes all of the relevant forces. Such questions are treated admirably by Mikhailovskii (1974) and Hasegawa (1975), and are not of primary concern in the present work. Similarly, the structure of planetary ionospheres is well covered by Bauer (1973) and is not addressed in detail here. Finally, the subject of traveling interplanetary discontinuities is best summarized by Burlaga (1974) and the references cited by him. Such phenomena are undoubtedly important in their cumulative effect upon the medium, but the major emphasis of the present work is on permanent structures (plasma boundaries) having fairly definite locations in space.

MAGNETOPAUSE

The traditional calculation of the shape of the magnetopause (Midgley and Davis, 1963; Mead and Beard, 1964) postulates a specular reflection of the incident solar wind. Such an approach proves useful in many applications but it discounts (a) the effects of particle gyration and drift within the magnetosphere and (b) the effects of collective behavior by the incident solar wind plasma. When the incident solar-wind protons and electrons are allowed to enter the magnetosphere and gyrate, it is found (Bird and Beard, 1972) that many of them become quasi-trapped by the geomagnetic field and drift across the equatorial nightside magnetosphere. The direction of drift is like that in the ring current (yielding a westward current in the earth's and Mercury's magnetospheres, eastward in Jupiter's), and so has the effect of elongating field lines that emanate from the polar regions. Thus, the Vlasov-equilibrium magnetosphere already contains an incipient magnetic tail, although its field lines are not quite "open". Incidentally, the superposi-

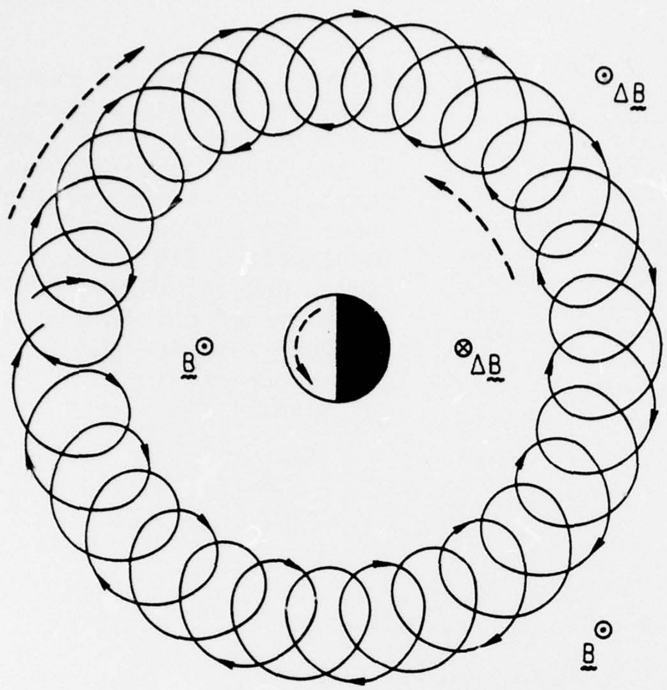

Figure 2. Schematic representation of the gyration and azimuthal drift (solid curve) of an equatorially mirroring proton, with associated current patterns (dashed arrows) and magnetic field perturbations ($\Delta\mathbf{B}$).

tion of gyration and drift currents can lead to an opposing current density at the inner edge of a current sheet (see Figure 2).

The observation (Ness et al., 1964; 1975; Wolfe et al., 1974) of a bow shock upstream from each planetary magnetopause casts doubt on the fundamental validity of an individual-particle approach to the magnetopause problem. Thus, Spreiter et al. (1966) have examined the opposite extreme: a gas-dynamical model of the interaction. The individual-particle and gas-dynamic approaches are likely to bracket the truth of the matter. Although neither approach appears justified fundamentally, the collective behavior of a collisionless plasma should lie somewhere between these opposite extremes.

In addition to the above aspects, however, there is also a dissipative (frictional) aspect to the interaction between solar wind and magnetosphere. This arises essentially because of instabilities in the conceptual Vlasov equilibrium outlined above, in which the solar-wind plasma is streaming relative to the stationary magnetospheric plasma. The two plasmas overlap somewhat because of particle gyration, and this spatial overlap allows them to interact in the boundary layer. Eviatar and Wolf (1968) have analyzed one such instability, in which the relative flow velocity is parallel to the magnetic field $\mathbf{B}$. One might reasonably expect an even stronger instability on those portions of the magnetopause where the relative flow velocity has a component normal to $\mathbf{B}$, and especially so if the interplanetary magnetic field is antiparallel to the magnetospheric $\mathbf{B}$ field there. Such instabilities are well-known in the laboratory (e.g., Barrett et al., 1972), and the consequences of antiparallel interplanetary and geomagnetic $\mathbf{B}$ fields are well-known in space (e.g., Crooker, 1975). Mendillo and Papagiannis (1971) have offered a semiquantitative description of the manner in which such instabilities can generate (via charge separation) a magnetospheric electric field that drives sunward "convection" on closed field lines. Stern (1973; 1975) has shown how

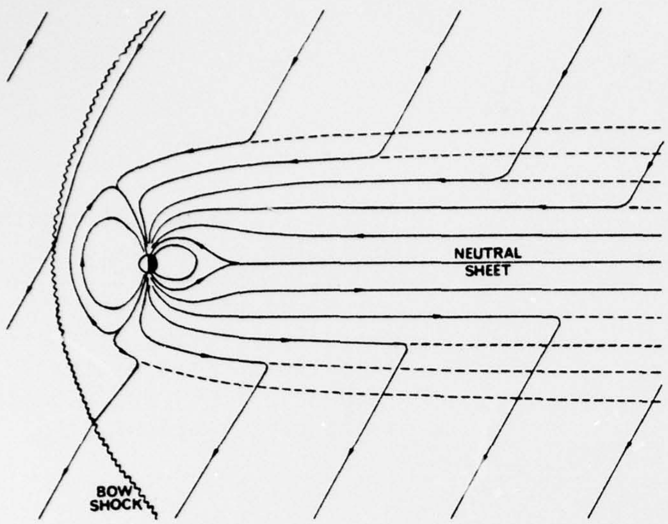

Figure 3. Schematic representation of interplanetary and geomagnetic field lines in the "open" model (solid curves) and in the "closed" model (dashed curves). Interplanetary field lines (solid curves) depart from the plane of the diagram at the magnetopause (outermost dashed curves) in the "closed" model.

the connection of magnetospheric B-field lines to "moving" interplanetary magnetic field lines can generate such an electric field in the magnetosphere.

Dissipation at the magnetopause tends to blur the classical distinction (e.g., Anderson, 1970) between the "closed" and "open" models of the magnetosphere. Interplanetary field lines in the "closed" model are draped around an identifiable magnetospheric surface, such that none can be traced to an intersection with the earth. Conversely, all tail field lines in the "open" model ultimately become interplanetary field lines, with the consequence that those emanating from the appropriate polar cap of the earth can be traced to an intersection with the sun (see Figure 3). The distinction is susceptible to theoretical analysis. If one were to prepare a dissipationless "equilibrium configuration" as this is usually understood in plasma kinetic theory, it would have to be the "closed" model. The "open" model, by contrast, is inherently dissipative. However, the "closed" model is probably unstable, and the associated instabilities lead to spatial and temporal fluctuations of the current density on the boundary (i.e., on the magnetopause). The magnetic fields associated with these fluctuations combine with the equilibrium magnetic field to form a new configuration in which as many as half of the tail field lines may be "open" at any given time. The other half at least will be closed, but the field-line connections are random. There is no way to predict precisely which tail field lines will be "open" and which will be "closed" to interplanetary access.

BOW SHOCK AND HELIOPAUSE

The bow shock (see Figure 1) is evidence of collective plasma behavior. Its location can be predicted quite adequately by means of fluid theory (Spreiter et al., 1966), but it is much thinner than the ordinary collisional mean free path, as given (for example) by Spitzer (1962). The observed thickness is determined by an effective mean free path (ℓ) of the plasma's constituent particles in the presence of plasma turbulence generated in the shock front. However, the effective mean free path upstream from the shock is very long, and so there is nothing to prevent magnetosheath- or shock-associated particles from traveling far upstream. Such upstream particles are readily observed in front of the earth's bow shock (Anderson, 1969; Lin et al., 1974; Reasoner, 1975). Indeed, particles associated with Jupiter's bow shock have even been observed on a spacecraft at $r \sim 1$ AU when the spacecraft was connected to Jupiter by an interplanetary magnetic field line (Krimigis et al., 1975; Mewaldt et al., 1975).

The heliopause (or heliosphere boundary) has not yet been observed in situ. It is a shock that should form at $r \sim 100$ AU, where the dynamical pressure of the solar wind is balanced by the pressure of the interstellar plasma, cosmic-ray gas, and magnetic field, rather than by the magnetic field of a planet. An outstanding review of this subject is given by Axford (1972). For the heliopause to be observable by future spacecraft, it must generate enough plasma turbulence to produce an effective mean free path $\ell \ll 100$ AU. Experience with various planetary bow shocks, however, leaves little doubt that the boundary of the heliosphere will in fact be observable.

INTERPLANETARY SECTOR BOUNDARY

Pneuman and Kopp (1971) have described the magnetohydrodynamic (MHD) expansion of hot plasma from a nonrotating sun with a magnetic dipole moment. Their result corresponds to the streamline (and interplanetary $\mathbf{B}$-field) configuration shown in Figure 4. An annular current sheet perpendicular to the

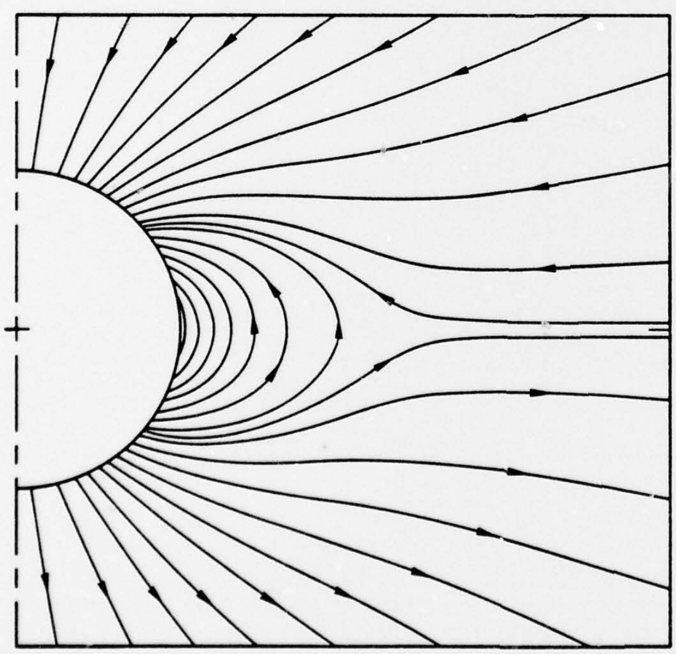

Figure 4. Deformation of a dipole field from within by an idealized solar wind, including formation of annular neutral sheet. Model is symmetric about the dipole axis (dashed line), but solar rotation is neglected in order to make B_ϕ vanish. Field and streamline distribution is based on a numerical MHD calculation by Pneuman and Kopp (1971). Arrows indicate direction of $\mathbf{B}$.

dipole axis separates adjacent regions of oppositely directed $\underset{\sim}{B}$. It is a neutral sheet (a surface on which $\underset{\sim}{B} = \underset{\sim}{0}$) in the limit shown. The magnitude of $\underset{\sim}{B}$, however, has a nonvanishing limit as one approaches the neutral sheet from above or below.

It is tempting to identify the neutral sheet of the Pneuman-Kopp model topologically with the "boundaries" that separate "sectors" of opposite polarity (sgn B_r) in observations (Wilcox and Ness, 1965) of the interplanetary magnetic field. The neutral sheet would necessarily be warped by higher multipoles (e.g., the quadrupolar component) of the solar $\underset{\sim}{B}$ field (Schatten, 1971; Schulz, 1973; Svalgaard et al., 1974) and tilted by any inclination between the dipole axis and the rotation axis. These effects in combination are qualitatively able to account for the various "sector" patterns commonly observed, and also lead naturally to the observed correlation (Rosenberg and Coleman, 1969) between sgn B_r and heliographic latitude. Moreover, the sector boundary (used in the singular, in view of Figure 4) in this model is part of the boundary between closed and open field lines. Since the solar-wind flow velocity $\underset{\sim}{u}$ vanishes along the closed field lines, it would not be surprising to find a smaller velocity $\underset{\sim}{u}$ along the open field lines immediately adjacent to the sector boundary (neutral sheet) than at higher heliographic latitudes. Such a variation of $\underset{\sim}{u}$ with latitude is indeed a property of the MHD model (Pneuman and Kopp, 1971) and is also observed in space (Wilcox, 1968) in the sense that $\underset{\sim}{u}$ is appreciably larger in mid-sector than near a "sector boundary".

Neutral sheets in space are subject to electromagnetic plasma instabilities which are collisionless variations on the "tearing mode" of Furth et al. (1963). The details are poorly known and may involve a hierarchy of instabilities (Coroniti and Eviatar, 1975) in which small-scale turbulence simulates the plasma resistivity required in the theory of Furth et al. (1963). Alternatively, there may be a "bootstrap" mechanism whereby the "tearing mode" itself creates the anomalous resistivity. The effect of the "tearing mode" is to introduce random connections between field lines separated by the idealized neutral sheet, i.e., to broaden the region of field reversal and to override the condition that $\underset{\sim}{B} = \underset{\sim}{0}$ there. Despite the anomalous resistivity associated with these effects, the heliomagnetic sheet current cannot be driven (in the steady state, at least) by an azimuthal electric field. In view of the azimuthal symmetry of the problem, such an electric field must have a line integral $2\pi r E_\phi$ and so could arise only from a temporal variation of the magnetic flux enclosed by a heliocentric circle of radius r in the equatorial plane.

PLANETARY NEUTRAL SHEET

There is a superficial resemblance between Figure 4 and a similar view (Dessler and Juday, 1965; Ness, 1969) of the night side of a planetary magnetosphere. Planetary neutral sheets should be subject to about the same instabilities as interplanetary ones. However, planetary neutral sheets are not azimuthally symmetric. They are limited in longitude, and (once the aforementioned dissipative interaction between the solar wind and magnetopause has been "turned on") they are subjected to an electrostatic field in the direction of the sheet current. Such an electric field tends to make the plasma sheet thinner than it otherwise would be, since the electric field causes plasma convection (drift at velocity $c\,\mathbf{E} \times \mathbf{B}/B^2$) toward the region of field reversal. The plasma sheet is *observed* to become thinner in the early stages of a magnetospheric substorm (*e.g.*, Siscoe, 1975). Perhaps this is a direct result of the increased $\mathbf{E}$ that must accompany the increased dissipation of solar wind at the magnetopause when the interplanetary $\mathbf{B}$ field acquires a southward component (opposing the generally northward geomagnetic field at the boundary). If one seeks to analyze the stability of a planetary neutral sheet, the presence of the azimuthal electric field $\mathbf{E}$ (parallel to the sheet) leads to a Vlasov equilibrium that is highly non-uniform in the direction of $\mathbf{E}$ (Cowley, 1973). The observed plasma sheet is not at all like this, but instead resembles superficially the uniform plasma column of a gaseous discharge (*e.g.*, Brown, 1959). This analogy suggests that the ultimate instability analysis of the plasma sheet must include the anomalous resistivity due to plasma turbulence as part of the "equilibrium", as in the "bootstrap" approach mentioned above. Incidentally, Bowers (1973) has shown that the Cowley (1973) equilibrium is subject to a two-stream instability.

PLASMAPAUSE

It proves convenient (and reasonably accurate) to derive the aforementioned electrostatic field $\mathbf{E}$ from a potential of the form $V(L,\phi) = (L/L^*)^n \times E_1 L^* a \sin\phi$, where $n = 2$ for $L \leq L^*$ and $n = -1/2$ for $L \geq L^*$ (Volland, 1975). The parameter *a* represents the planetary radius, and the ordered pair (L,ϕ) identifies a field line. There is a discontinuity in the meridional component of $\mathbf{E}$ at $L = L^*$ in this model.

Cold-plasma drift trajectories are identified by superimposing upon $V(L,\phi)$ the potential $(-\Omega a^2 B_0/cL)$ associated with planetary rotation (angular velocity $\boldsymbol{\Omega}$), where $B_0 a^3$ is the planetary magnetic moment and c is the speed of light, and seeking equipotentials of the total. One of these equipotentials is singular in the sense that it separates equipotentials that can intersect $L = L^*$ from those that cannot. The singular equipotential (which is usually identified with the plasmapause in theoretical analyses) can be found by locating the point at which the total electric field (convection plus rotation) vanishes in the dawn-dusk meridian ($\phi = \pm\pi/2$). If there is no such point, then the singular equipotential is that which just grazes $L = L^*$ along this meridian and on which $L \leq L^*$ at all other longitudes. Siscoe and Chen (1975) have introduced the term "omegapause" for the singular equipotential (and "omegasphere" for the volume enclosed by it) in order to avoid tacit prejudgments concerning the *density* of cold plasma.

Most investigators prior to Volland (1975) had taken $n = 1$ and $L^* = \infty$ for analytical purposes. More complicated forms of $V(L,\phi)$ had been handled numerically, of course (*e.g.*, Wolf, 1975). However, it is found for arbitrary n that the above form of $V(L,\phi)$ yields a plasmapause that can be traced analytically as $\phi(L)$. Examples for $n = 1$ and $n = 2$ are shown in Figure 5 (*cf.* Roederer, 1970; Volland, 1975). A plasmapause that just grazes $L = L^*$ at $\phi = -\pi/2$ had been sketched qualitatively by Brice and Ioannidis (1970). This situation prevails at Jupiter, but not at the earth (except perhaps at

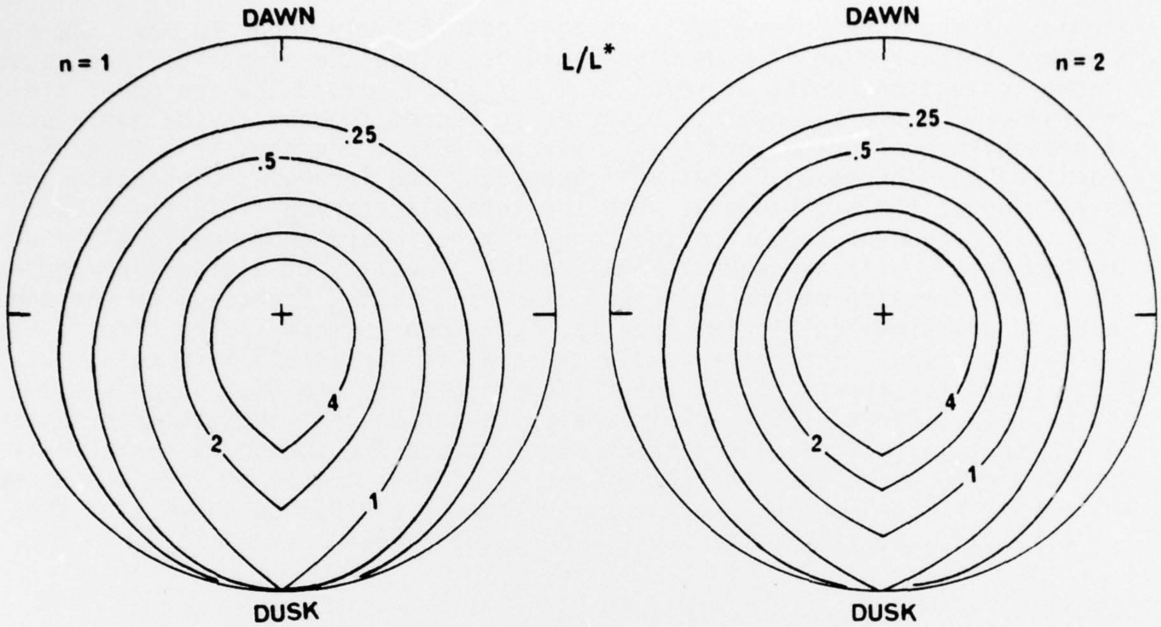

Figure 5. Polar plot, L/L^* vs. ϕ, of plasmapause locations (solid curves labeled by values of $cE_1L^{*2}/\Omega aB_0$) for two models of $V(L,\phi)$ on closed field lines ($L \leq L^*$).

times of extermely small K_p, the index of geomagnetic activity). It is found in general that the case n = 2 corresponds more nearly than n = 1 to the observed shape of the earth's plasmapause. The model plasmapause becomes more nearly symmetric in azimuth (ϕ) as n is increased.

Drift boundaries analogous to the plasmapause can be identified also for particles of nonvanishing energy. Approximations for this purpose have been developed by Kivelson and Southwood (1975). Such drift boundaries may help to account for the configuration of the inner edge of the plasma sheet (shown schematically in Figure 1), which represents the limit of penetration for particles from the neutral-sheet region that have gained access (presumably by turbulent spatial diffusion) to the closed field lines that lie earthward of the cusp. Kennel (1969) proposes alternatively that particle precipitation via pitch-angle diffusion limits the convective access of the plasma sheet across closed field lines.

CONVECTION ON OPEN FIELD LINES

Although applied by Volland (1975) to a dipolar $\mathbf{B}$ field, the foregoing model for $V(L,\phi)$ arises naturally when one examines a $\mathbf{B}$-field model in which the polar field lines are open. One such model, namely $\mathbf{B} = B_0 \nabla[(a/r)^3 z - (2/3L^*)^3 z]$, was introduced by Dungey (1961) and has recently been resurrected (Stern, 1973; Hill and Rassbach, 1975) for study of the interaction between

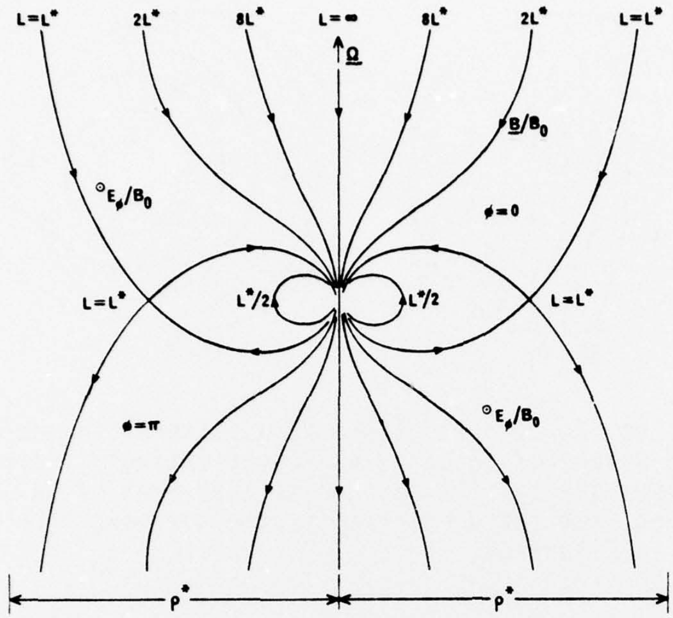

Figure 6. Meridional (noon-midnight) section of magnetospheric model used by Hill and Rassbach (1975) for mapping $\mathbf{E}$ and $\mathbf{B}$. Open field lines correspond to $L \geq L^*$, and the azimuthal (ϕ) component of $\mathbf{E}/B_0$ is directed as shown.

magnetosphere and solar wind. Representative field lines of the model are shown in Figure 6. The above form of $\mathbf{B}$ corresponds to a uniform field plus a dipole field. Many investigators interpret the uniform part as the interplanetary $\mathbf{B}$ field. Such an interpretation seems misleading, however, since it implies that the presence of a magnetospheric tail is contingent on an interplanetary field that is parallel (rather than antiparallel) to the dipole axis ($-\hat{\mathbf{z}}$). It is more realistic to view $B_0(2/3L^*)^3$ as a magnetospheric parameter that depends only indirectly on the interplanetary field. Thus, one should view the surface defined by $L = L^*$ at $r \geq 3L^*a/2$ as the magnetopause and postulate a field $\epsilon\mathbf{B}$ outside the magnetopause, where ϵ ($\lesssim 1$ in absolute value) is a constant. The interplanetary field thus has an asymptotic intensity $\mathbf{B}_i = -\epsilon B_0(2/3L^*)^3\hat{\mathbf{z}}$, and the discontinuity in magnetic field at the magnetopause is supported by azimuthal currents flowing on the magnetopause. The case $\epsilon < 0$ corresponds to an interplanetary field that is antiparallel to the dipole axis, but the magnetosphere has a tail nevertheless. The case illustrated in Figure 6 corresponds to $\epsilon = 0$, since it shows no field lines ($\mathbf{B} \equiv \mathbf{0}$) outside the magnetosphere.

The potential $V(L,\phi) = (L/L^*)^{-1/2}E_1L^*a \sin\phi$ postulated by Volland (1975) for $L \geq L^*$ corresponds to an asymptotically uniform electric field $\mathbf{E} = -0.3849E_1\hat{\mathbf{y}}$ across the tail of the magnetosphere (Hill and Rassbach, 1975). The distance from the axis of the tail (i.e., from the field line $L = \infty$) is given asymptotically by $\rho = (3L^*/L)^{1/2}(3L^*a/2)$. This means that $(L^*/L)^{1/2}$ and ϕ are natural polar (cylindrical) coordinates for tracing drift trajectories in the tail. Cold-plasma trajectories are identified as above by tracing the equipotentials of $V'(L,\phi) \equiv V(L,\phi) - (\Omega a^2 B_0/cL)$. They turn out to be concentric circles offset from the axis of the tail (see Figure 7). The circles degenerate to straight lines in the limit of a nonrotating planet (approximated by Mercury). The plasma drift on open trajectories (those that intersect $L = L^*$) is directed from day toward night, i.e., toward the portion of the magnetospheric surface ($L = L^*$) that is topologically equivalent to

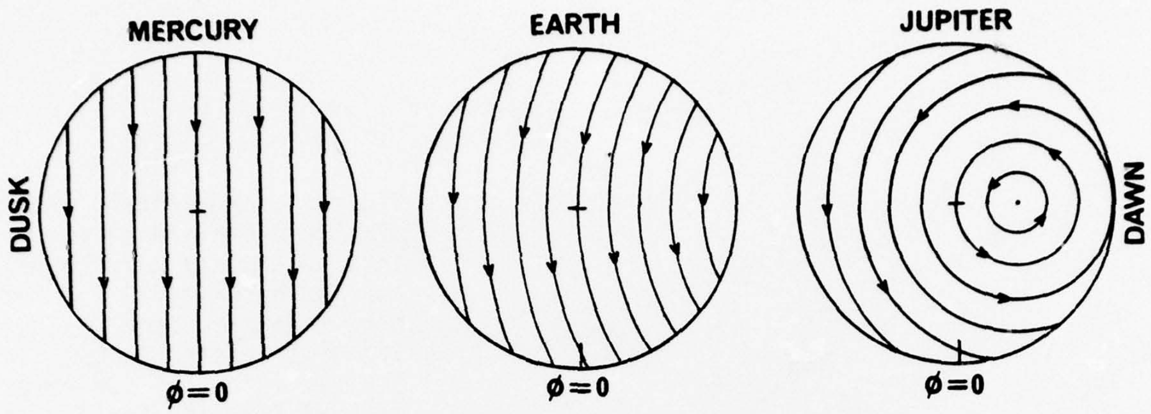

Figure 7. Polar plot, $(L^*/L)^{1/2}$ vs. ϕ, of cold-plasma flow patterns in the magnetospheric tail for selected values of $cE_1L^{*2}/\Omega aB_0$ (qualitatively representative of the three planets indicated). The pattern is that seen by an observer looking toward the planet from far downstream in the northern lobe of the tail (i.e., from z = +∞ in Figure 6).

the neutral sheet. If one scales to the various magnetospheric parameters of Jupiter, it is found that a major portion of the zenomagnetic tail is adiabatically isolated from the usual plasma source (solar wind and magnetosheath). In other words, the common center of Jovian plasma-drift paths is found to lie well inside the tail. One might conclude, other things (such as B_0a^3) being equal, that a nonrotating Jupiter would have had a much denser tail plasma. Alternatively, one might look to planets such as Jupiter (in which rotation dominates convection) for examples of tail plasma derived largely from the planetary ionosphere (Axford, 1970) rather than from the solar wind.

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